TM 80-1 SA

Technical Memorandum

EVALUATION OF AIR-TO-GROUND WEAPON DELIVERY SYSTEMS PERFORMANCE

Mr. Russell D. Newberry
Weapon Systems Analyst

Strike Aircraft Test Directorate

18 April 1980

Approved for Public Release; Distribution Unlimited.

DEPARTMENT OF THE NAVY
NAVAL AIR TEST CENTER

NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TM 80-1 SA	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF AIR-TO-GROUND WEAPON DELIVERY SYSTEMS PERFORMANCE		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) MR. RUSSELL D. NEWBERRY		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVAL AIR TEST CENTER STRIKE AIRCRAFT TEST DIRECTORATE PATUXENT RIVER, MARYLAND 20670		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS NAVAL AIR TEST CENTER NAVAL AIR STATION PATUXENT RIVER, MARYLAND 20670		12. REPORT DATE 18 APRIL 1980
		13. NUMBER OF PAGES 39
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

WEAPON DELIVERY ACCURACY
CEP
STATISTICAL ANALYSIS
DATA ANALYSIS
FLIGHT TEST

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The overall performance of a given attack mission system is determined from scoring of each weapon impact with the weapon usually scored in an in-range and cross-range coordinate system. An explanation of why the weapons impacted as they did requires that the major sources of error be determined and examined. This technical memorandum presents a method to isolate and examine weapon system error sources and their effect on weapon impact miss distances.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

This Technical Memorandum presents an overview of the analysis of weapon delivery system accuracy, specifically, attack mission systems installed in Strike aircraft. This entails determining how accurately a given attack weapon system performed and also requires answering why the demonstrated performance occurred. Presented herein is a method to isolate weapon system error sources and determine their effect upon weapon impact miss distance.

APPROVED FOR RELEASE

J. G. WISSLER, RADM, USN
Commander, Naval Air Test Center

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

DESCRIPTION OF WEAPON SYSTEM ANALYSIS

1. Weapon system analysis is the correlation of weapon system errors and weapon impact miss distances. Isolation of weapon system error sources and their effect on weapon impact miss distances is the prime objective. To isolate weapon system errors, weapon system derived information is correlated and compared to true information. This is done by flying weapon delivery flights on a test range that provides time versus space position. Once an error source is isolated, its effect on impact miss distance is calculated, thereby obtaining the error source and error source effect. After this is done on all error sources, the impact miss distance can be described in terms of error source effects, thereby providing a correlation between weapon impact miss distances and weapon system errors.

REASONS TO CONDUCT WEAPON SYSTEM ANALYSIS

2. Weapon system analysis should be conducted on a weapon system under test whether performance is unsatisfactory or satisfactory. Naturally, when a weapon system's performance is unsatisfactory, the error source inducing the performance should be isolated for decisions on corrections. When performance is satisfactory, previous error sensitivity studies can be confirmed, thereby shortening the test program by reducing the number of flights needed, or compensating error may exist. Without weapon system analysis, compensating errors would go unnoticed until a hardware or software change was implemented in the aircraft, resulting in weapon system performance degradation. Weapon system analysis is necessary to isolate compensating errors which allows intelligent decisions with respect to hardware or software changes and their effect on weapon system performance.

TEST REQUIREMENTS TO PERMIT WEAPON SYSTEM ANALYSIS

3. An instrumented aircraft and test flights flown on an instrumented range are required to permit weapon system analysis. The aircraft instrumentation records sensor inputs to the weapon delivery computer, interim calculations within the weapon delivery computer, and outputs from the weapon delivery computer. The instrumented test range should provide position of the aircraft accurate to within 3 to 5 ft, velocity of the aircraft accurate to within 1 to 2 ft/sec, and an atmospheric profile from target altitude to the altitude at which weapon release occurred. The atmospheric profile provides pressure, temperature, and winds accurate to within 1 to 2 ft/sec. To permit the comparison of weapon system data and instrumented range data, time correlation accurate to within 3 to 5 msec is necessary. When an event occurs in the weapon system, it must be marked at the proper time on the instrumented range data. Since an aircraft flies in the range of 750 ft/sec, it can be seen that 3 to 5 msec time correlation is necessary to maintain data comparison accuracy similar to space position accuracy and velocity accuracy. The preceding requirements are necessary to conduct a weapon system analysis.

DISCUSSION

COORDINATE SYSTEMS

4. Three coordinate systems will be used in the following discussion. Instrumented range data are computed in the East/North Earth coordinate system; weapon impacts are scored in a system defined as the Weapon Impact coordinate system; and the weapon system releases weapons in an Airmass coordinate system. A short treatment of each coordinate system follows before discussing weapon systems analysis.

East/North Earth Coordinate System

5. Essentially, all instrumented range data are computed in the East/North coordinate system since all of the devices to sense the aircraft's position and movement are tied to the earth. The target is usually at the center of the coordinate system with East/North constituting a normal cartesian coordinate system (see figure 1). Vertical distances are positive upward. The position of the aircraft and weapon imapcts are output relative to the target in East/North coordinates. The velocities of the aircraft are computed as north, east, and vertical. The velocity of the wind is also computed as east and north components. Zero vertical wind is normally assumed. From these instrumented range calculations, selected comparison parameters can be calculated and compared to weapon system parameters with the exception of attitude parameters.

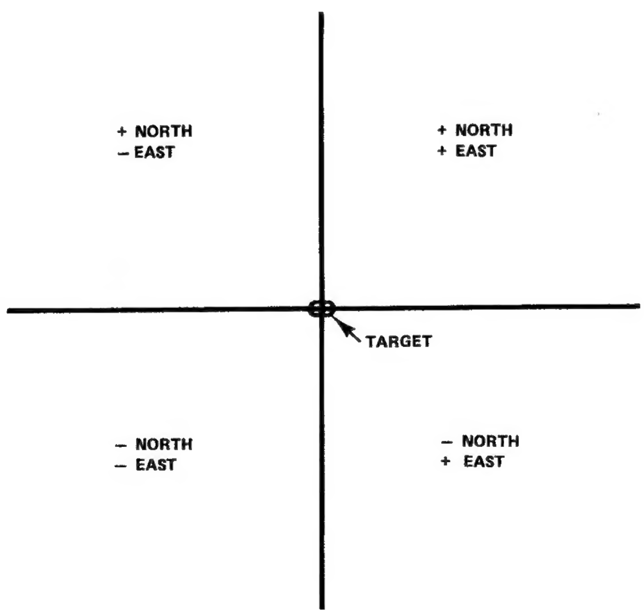

Figure 1
East/North Earth Coordinate System

Weapon Impact Coordinate System

6. Weapon impacts scored in the East/North Earth coordinate system are not very descriptive of the weapon system performance when the aircraft is flown in a direction other than north. Therefore, weapon impacts are rotated into the weapon impact coordinate system. To obtain the rotation angle, the east and north positions of the aircraft, at weapon release, must be measured relative to the target. The rotation angle is the arctan of the east aircraft distance divided by the north aircraft distance. The east and north coordinates of the weapon impact is then rotated by this angle into the weapon impact coordinate system. See example 1 and figure 2 for elaboration of this procedure.

Example: 1

Given: Aircraft east distance 2662 ft

Aircraft north distance -6652 ft

Weapon Impact -225 ft North
-133 ft East

Find rotation angle

$$\mathrm{Tan}^{-1}\,(2662'/-6652') = -21.8^{\circ} = \text{rotation angle}$$

Rotate weapon impact into impact coordinate system

$$\text{Long impact} = (-225'\cos -21.8^{\circ} + (-)\ 133'\sin -21.8^{\circ}) = -160'$$

$$\text{Right impact} = (-133'\cos -21.8^{\circ} - (-)\ 225'\sin -21.8^{\circ}) = -207'$$

Note: The long or short component of weapon impact is usually called the in-range component and the left or right component of weapon impact is usually called the cross-range component.

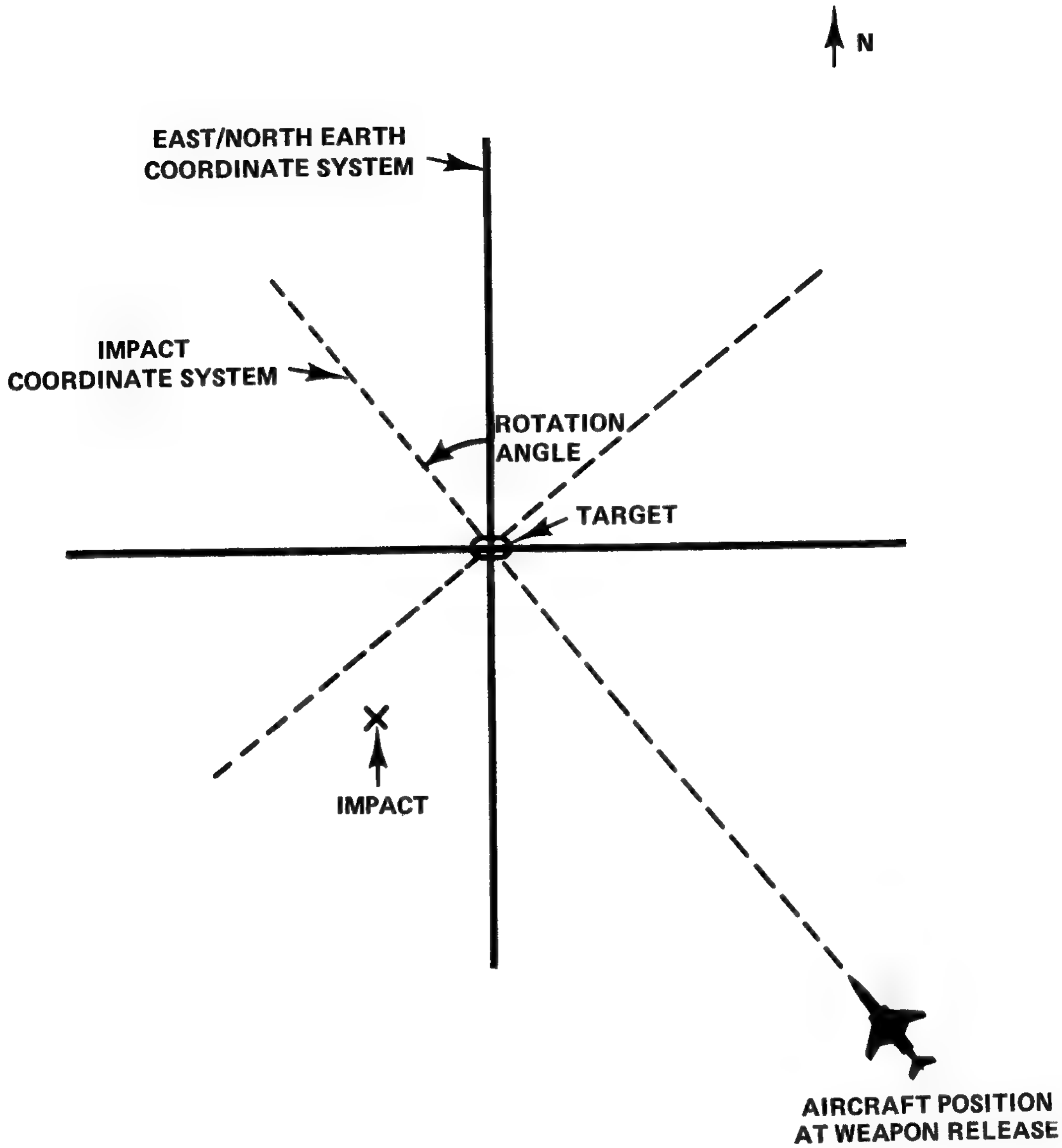

Figure 2
Weapon Impact Coordinate System

Airmass Coordinate System

7. Since the aircraft is flying in the Airmass, a weapon release point is also calculated in the Airmass coordinate system. Error source effects are, therefore, calculated in this coordinate system, requiring a determination of the angle for rotation of the aircraft to target distances. To obtain the rotation angle, calculate the arctan of the east velocity minus the east wind divided by the north velocity minus the north wind. See example 2 and figure 3 for a rotation of the north and east distances from the aircraft to target into in-range and cross-range airmass distances to the target.

Example: 2

Given: North velocity 612 ft/sec

East velocity -266 ft/sec

North wind velocity -21 ft/sec

East wind velocity 10 ft/sec

North distance to the target -6652 ft

East distance to the target 2662 ft

Find rotation angle for the East/North Earth to Airmass rotation.

$$\text{Rotation angle} = \text{Tan}^{-1}\ ((-266\ -10)/(612-(-21))) = -23.6^{\circ}$$

Find in-range distance from the aircraft to the target. Since the aircraft is in the second quadrant and flying toward the target, the sign of the north and east distances from the instrumentation range data is changed. This is done to compute instrumeted range data in the same sign convention as the weapon system data. Therefore, the equations for the in-range and cross-range airmass distances to the target are as follows:

$$\text{In-range distance} = (6652'\cos -23.6^{\circ} + (-2662'\sin -23.6^{\circ})) = 7162'$$

$$\text{Cross-range distance} = (-2662'\cos -23.6^{\circ} - 6652'\sin -23.6^{\circ}) = -219'$$

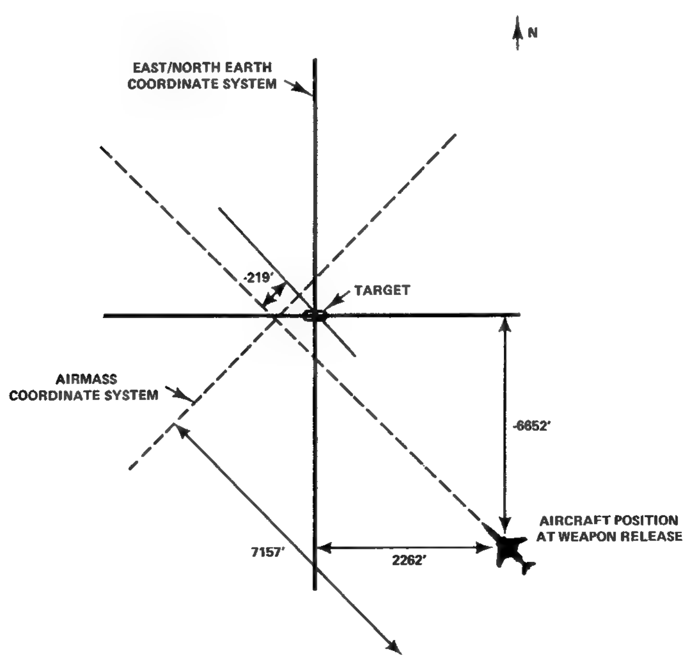

Figure 3
Airmass Coordinate System

ERROR SOURCE EFFECTS ANALYSIS

8. The in-range and cross-range error sources are analyzed separately. This is done to isolate the error sources effecting the respective in-range and cross-range components of the impact miss distance. The in-range error source effects analysis will be discussed first followed by the cross-range error source effects analysis discussion.

IN-RANGE ERROR SOURCE EFFECTS ANALYSIS

9. Eight error sources are discussed in this section. Once each error source is discussed and its effect on the weapon impact is obtained, the eight error source effects will be summed and compared to the in-range component of the weapon impact.

In-Range Bomb Deviation

10. Due in part to manufacturing tolerances (weight, center of gravity, and surface conditions), bent fins, and differences in ejection racks, any two bombs given the same release conditions will not follow identical trajectories. Analyzing a weapon system requires that impact errors induced by anomalies in the bomb and bomb trajectories be examined and removed. To ascertain the impact error induced by an imperfect bomb, a theoretical trajectory is calculated from the point of weapon release to weapon impact. Inputs used in the trajectory calculation are from the data gathered by the instrumented range. The trajectory calculation yields the in-range distance a perfect bomb should have traveled. The actual in-range distance the bomb traveled is obtained from the instrumented range data. The theoretical in-range bomb travel is compared to the actual in-range bomb travel to obtain bomb deviation. Example 3 and figure 4 demonstrate impact error induced by bomb deviation.

Example: 3

Given: North velocity 612 ft/sec

East velocity -266 ft/sec

Vertical velocity -350 ft/sec

North wind velocity -21 ft/sec

East wind velocity 10 ft/sec

North distance to the target -6652 ft

East distance to the target 2662 ft

Vertical distance to the target 5500 ft

Vertical flight path angle -26.9°

Actual down-range bomb travel 6820 ft

The distance in range the bomb traveled after release was 6820 ft. The theoretical in-range distance calculated from the theoretical trajectory was 6909 ft. The difference was -89 ft, which is the in-range weapon impact error due to bomb deviation.

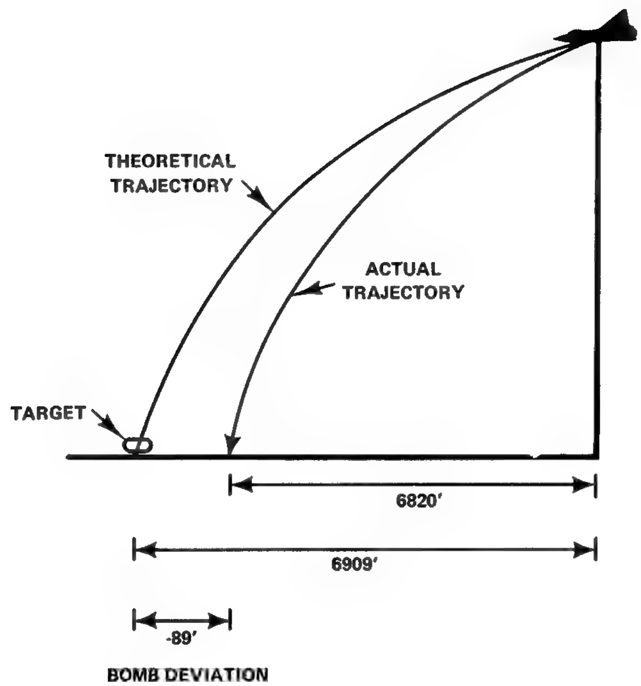

Figure 4
In-Range Bomb Deviation

In-Range Target Position Error

11. To accurately deliver bombs on target, the weapon system must determine the target position relative to the aircraft. To obtain in-range target position error, an in-range target position is first calculated from instrumented range data. In-range target position is calculated by rotating the north and east ranges from the East/North Earth coordinate system into the Airmass coordinate system. Now the in-range target position can be compared to the weapon system in-range target position.

12. Some aircraft instrumentation systems do not output the in-range distance to the target. If this is the case, the north range to the target from the instrumented range is compared to the north range to the target derived by the weapon system. Also, the east range to the target from the instrumented range is compared to the east range to the target derived by the weapon system. These two differences can then be rotated from the East/North Earth coordinate system into the Airmass coordinate system to obtain the respective target position errors. Example 4 and figure 5 further explain this procedure.

Example: 4

Given: North distance to the target -6652 ft

East distance to the target 2662 ft

Rotation angle from East/North Earth to Airmass -23.6°

Weapon system measured north distance to the target 6672 ft

Weapon system measured east distance to the target -2677 ft

Find the weapon system in-range target position error. First the sign of the east and north distances are changed to compute instrumented range data in the same sign convention as the weapon system.

6672'	Weapon system north range
-6652'	North range
20'	Weapon system north range error
-2677'	Weapon system east range
-(-)2662'	East range
-15'	Weapon system east range error

Rotate East/North Earth position error into the Airmass coordinate system.

$$\text{In-range error} = (20'\cos -23.6^{\circ} + (-15'\sin - 23.6^{\circ})) = 24'$$

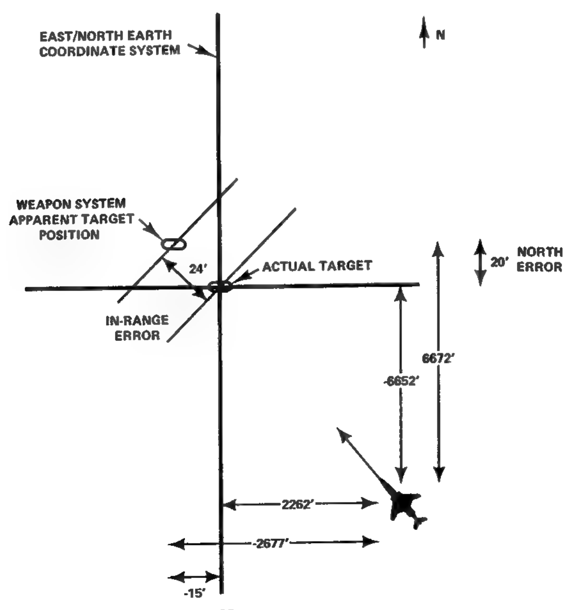

Figure 5
In-Range Target Position Error

Trajectory Calculation Errors

13. Four inputs are needed by the weapon delivery computer to calculate an in-range bomb trajectory. These inputs are altitude, true airspeed, vertical flight path angle, and wind. Since these four error sources are in the trajectory calculation, the procedure for calculating these error effects is similar to calculating the error effect of bomb deviation. The weapon system releases the weapon when the calculated trajectory is equal to the weapon system derived in-range distance to the target. Table I shows the effects of each of these inputs on weapon impact along the line of flight. Figures 6 through 9 and examples 5 through 8 present the procedures for examining these four error sources and their effect on in-range impact miss distance.

Table I

Error Source Effects Along the Flight Path

Error Source	Error (Aircraft-True)	Error Source Effect on Weapon Impact
Altitude	high low	short long
True Airspeed	fast slow	short long
Vertical Flight Path Angle	high low	long short
Wind	greater less	short long

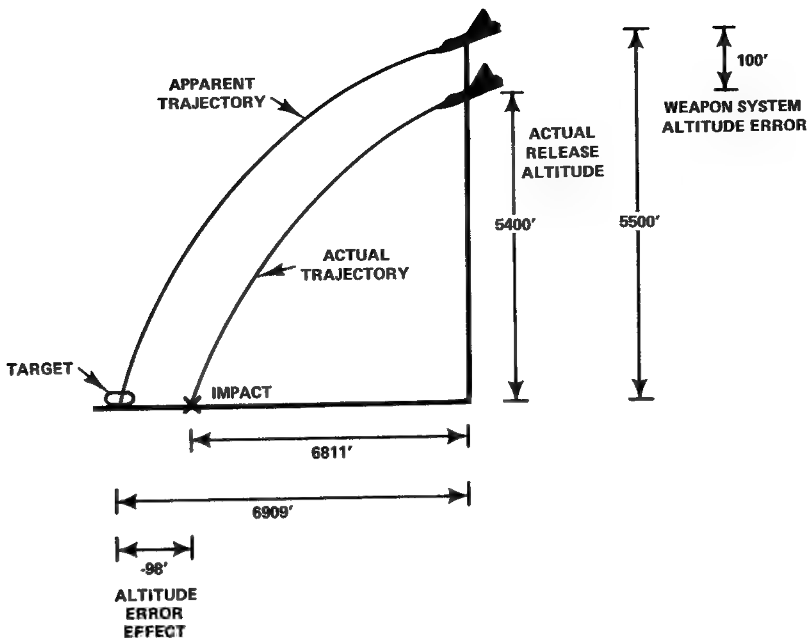

Figure 6
In-Range Altitude Induced Error

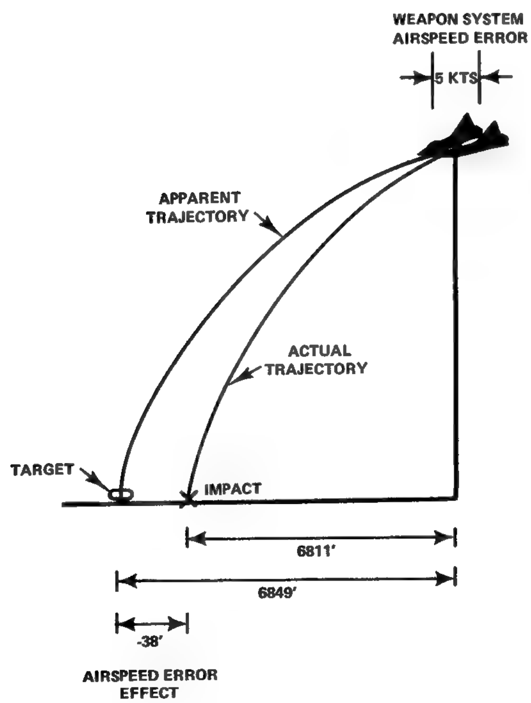

Figure 7
In-Range True Airspeed Induced Error

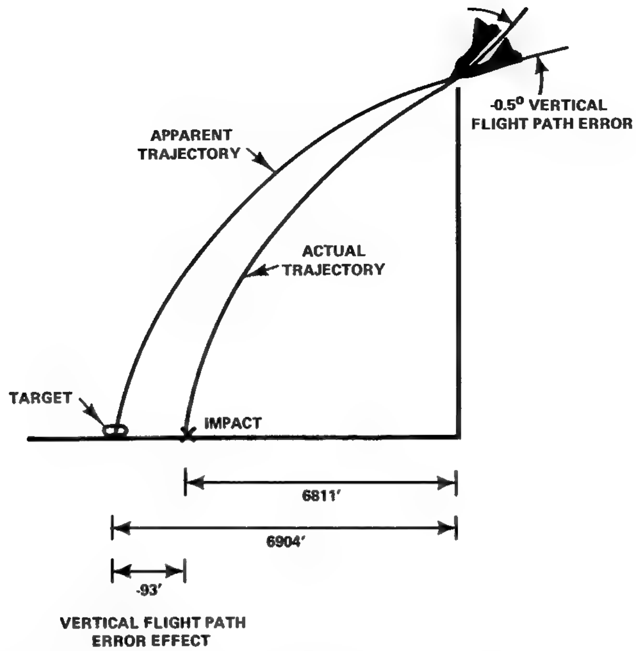

Figure 8
In-Range Vertical Flight Path Angle Induced Error

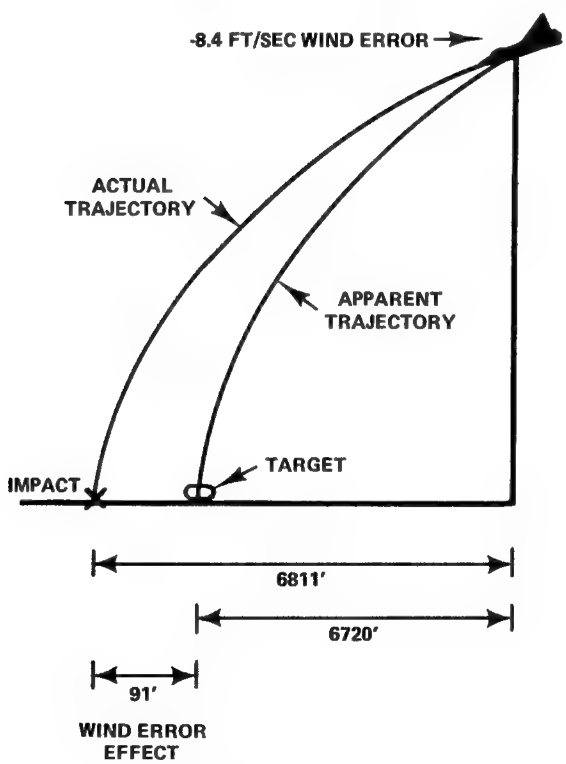

Figure 9
In-Range Wind Induced Error

Altitude Induced Error

Example: 5

Given: Altitude 5400 ft

True airspeed 461 kt

Vertical flight path angle -26.9^{o}

In-range wind -23 ft/sec

Inputs to the weapon system trajectory calculation

Altitude 5500 ft

True airspeed 461 kt

Vertical flight path angle -26.9^{o}

In-range wind -23 ft/sec

From the information given, it can be seen the weapon system has 100 ft of altitude error.

Find the altitude induced weapon impact error. The in-range bomb travel computed from the actual release condition is 6811 ft and the in-range bomb travel computed from weapon system information is 6909 ft. Therefore, in this case, 100 ft of altitude error induced -98 ft of weapon impact error.

True Airspeed Induced Error

Example: 6

Given: Altitude 5400 ft

True airspeed 461 kt

Vertical flight path angle -26.9^{o}

In-range wind -23 ft/sec

Inputs to the weapon system trajectory calculation

Altitude 5400 ft

True airspeed 466 kt

Vertical flight path angle -26.9^{o}

In-range wind -23 ft/sec

From the information given, it can be seen the weapon system has a 5 kt true airspeed error.

Find the true airspeed induced weapon impact error. The in-range bomb travel computed from the actual release condition is 6811 ft and the in-range bomb travel computed from weapon system information is 6849 ft. Therefore, 5 kt of true airspeed error induced -38 ft of weapon impact error.

Vertical Flight Path Angle Induced Error

Example: 7

Given: Altitude 5400 ft

True airspeed 461 kt

Vertical flight path angle -26.9°

In-range wind -23 ft/sec

Inputs to the weapon system trajectory calculation

Altitude 5400 ft

True airspeed 461 kt

Vertical flight path angle -26.4°

In-range wind -23 ft/sec

From the information given, it can be seen the weapon system has -0.5° vertical flight path angle error.

Find the vertical flight path angle induced impact error. The in-range bomb travel computed from the actual release condition is 6811 ft and the in-range bomb travel computed from weapon system information is 6904 ft. Therefore, -0.5° of vertical flight path angle error induced -93 ft of weapon impact error.

Wind Induced Error

Example: 8

Given: Altitude 5400 ft

True airspeed 461 kt

Vertical flight path angle -26.9°

In-range wind -23 ft/sec

Inputs to the weapon system trajectory calculation

Altitude 5400 ft

True airspeed 461 kt

Vertical flight path angle -26.9°

In-range wind -31.4 ft/sec

From the information given, it can be seen the weapon system has a -8.4 ft/sec wind error.

Find impact error induced by the wind error. The effect in-range wind has on in-range bomb travel is wind multiplied by time of fall -23 ft/sec 10.8 sec = -249 ft. The effect the weapon system calculated was -31.4 ft/sec 10.8 sec = -340 ft. Therefore, -8.4 ft/sec wind error induced 91 ft of weapon impact error.

Observation on Trajectory Calculation Errors

14. Examination of the previous four examples demonstrates that, as an error effect is developed from each error source, the remaining three error sources were assumed to be error free. This was done to isolate each error source for individual examination. The four error sources are assumed to be independent and, therefore, the four error source effects can be summed to obtain the total trajectory calculation error effect (see example 9).

Example: 9

Given: From examples 5, 6, 7, and 8

Altitude induced error	-98 ft
True airspeed induced error	-38 ft
Vertical flight path angle induced error	-93 ft
In-range wind induced error	+91 ft
TOTAL TRAJECTORY CALCULATION INDUCED ERROR	-138 ft

15. The input error sources can also be broken into components for further examination. This will not be done in this discussion since each different weapon system may calculate the components to the trajectory calculation differently. A typical example is the calculation of vertical flight path angle. One weapon system calculates it by adding pitch and angle of attack. Another system calculates it by arctan of vertical velocity divided by the square root of ((north velocity - north wind) squared plus (east velocity - east wind) squared). As noted here, one system

used two parameters, the other system used five. Due to weapon system differences further break down of components of the trajectory calculation will not be done.

Ballistic Computation Error

16. An error may exist in the trajectory calculated by the weapon delivery system even though the input parameters are error free. This is due to the limited capacity of typical weapon delivery computers and the short amount of time allotted for trajectory calculation on a weapon delivery run. If an error exists, it can be determined by calculating a bomb trajectory on a large capacity ground based computer. For this calculation, the weapon system inputs are used. Then a comparison of the weapon system in-range bomb travel and the ground based computer calculation of bomb travel is made (see example 10).

Example: 10

Given: Weapon system trajectory calculation input parameters:

Altitude 5500 ft

True airspeed 466 kt

Vertical flight path angle -26.4°

In-range wind -31.4 ft/sec

Output from instrumented range trajectory calculation

In-range bomb travel 6951 ft

Output from aircraft instrumentation

In-range bomb travel 6931 ft

Find error:
$$\begin{array}{r} 6951 \text{ ft} \\ \underline{-6931 \text{ ft}} \\ 20 \text{ ft} \end{array}$$

In-range weapon impact error induced by an error in the weapon system trajectory calculation is 20 ft.

Release Prediction Error

17. As stated previously, the weapon system should issue a release when the in-range bomb travel from the trajectory calculation is equal to the in-range distance to the target. Otherwise, an in-range error occurs in the weapon impact. To obtain the error, compare the weapon system derived in-range bomb travel at release and the weapon system derived in-range distance to the target at release. The difference is in-range impact error induced by the error in release prediction (see example 11).

Example: 11

Given: In-range bomb travel from the weapon system trajectory calculation 6931 ft.

In-range distance from the aircraft to the target derived by the weapon system 6950 ft.

Difference:

	6950 ft
	-6931 ft
	19 ft

Nineteen feet is the release prediction error effect.

Total In-Range Error

18. The effect on the in-range component of impact miss distance is the sum of all in-range error source effects. The effect of the weapon system is the sum of all in-range error source effects less the effect of bomb deviation. Example 12 sums in-range error source effects.

Example: 12

Given:	Bomb deviation	-89 ft
	In-range target position	24 ft
	Altitude	-98 ft
	True airspeed	-38 ft
	Vertical flight path angle	-93 ft
	In-range wind	91 ft
	Ballistic computation	20 ft
	Release prediction	19 ft
	Total In-Range Error Effect	-164 ft

Residual Error

19. If the in-range error source effects analysis is perfect and the instrumented range data has no errors, the total in-range error source effect would be exactly equal to the in-range component of the weapon impact. Unfortunately, this is not the case. Small errors in the truth data and time correlation introduce small errors in the error source effects analysis. Therefore, total in-range error source effect does not match exactly the in-range component of the weapon impact. This difference between total in-range error effect and the in-range component of weapon impact is residual error (see example 13).

Example: 13

Given: From example total in-range error effect -164 ft.

In-range component of weapon impact miss distance -160 ft.

Find residual error:

	Total in-range error effect	-164 ft
	Impact miss distance	-(-)160 ft
	Residual Error	-4 ft

CROSS-RANGE ERROR SOURCE EFFECT ANALYSIS

20. Five error sources are discussed in this section. Each error source is examined and its effect on the cross-range component of the weapon impact is obtained. The five error source effects will be summed and compared to the in-range component of the weapon impact.

Cross-Range Bomb Deviation

21. For the same reasons discussed under in-range bomb deviation, impact errors induced by anomalies in the bomb and bomb release are examined. Cross-range bomb travel is calculated by multiplying cross-range wind by time of fall. Time of fall is an output from the bomb trajectory calculation. Comparing the cross-range distance the released bomb traveled to time of fall multiplied by cross-range wind obtains the impact error induced by bomb deviation. Example 14 and figure 10 present the calculation of cross-range wind and bomb deviation.

Example: 14

Given: North wind velocity -21 ft/sec

East wind velocity 10 ft/sec

Angle for rotation of East/North Earth to Airmass -23.6°

Find cross-range wind:

Tan^{-1} (10 ft/sec cos -23.6° - (-) 21 ft/sec sin -23.6°) = 1 ft/sec cross-range wind.

Given: Cross-range bomb travel 15 ft

Time of fall 10.5 sec

Find bomb deviation:

Theoretical cross-range bomb travel = 1 ft/sec 10.5 sec = 10.5 ft.

Actual cross-range bomb travel	15 ft
Theoretical cross-range bomb travel	-10.5 ft
Bomb Deviation	4.5 ft

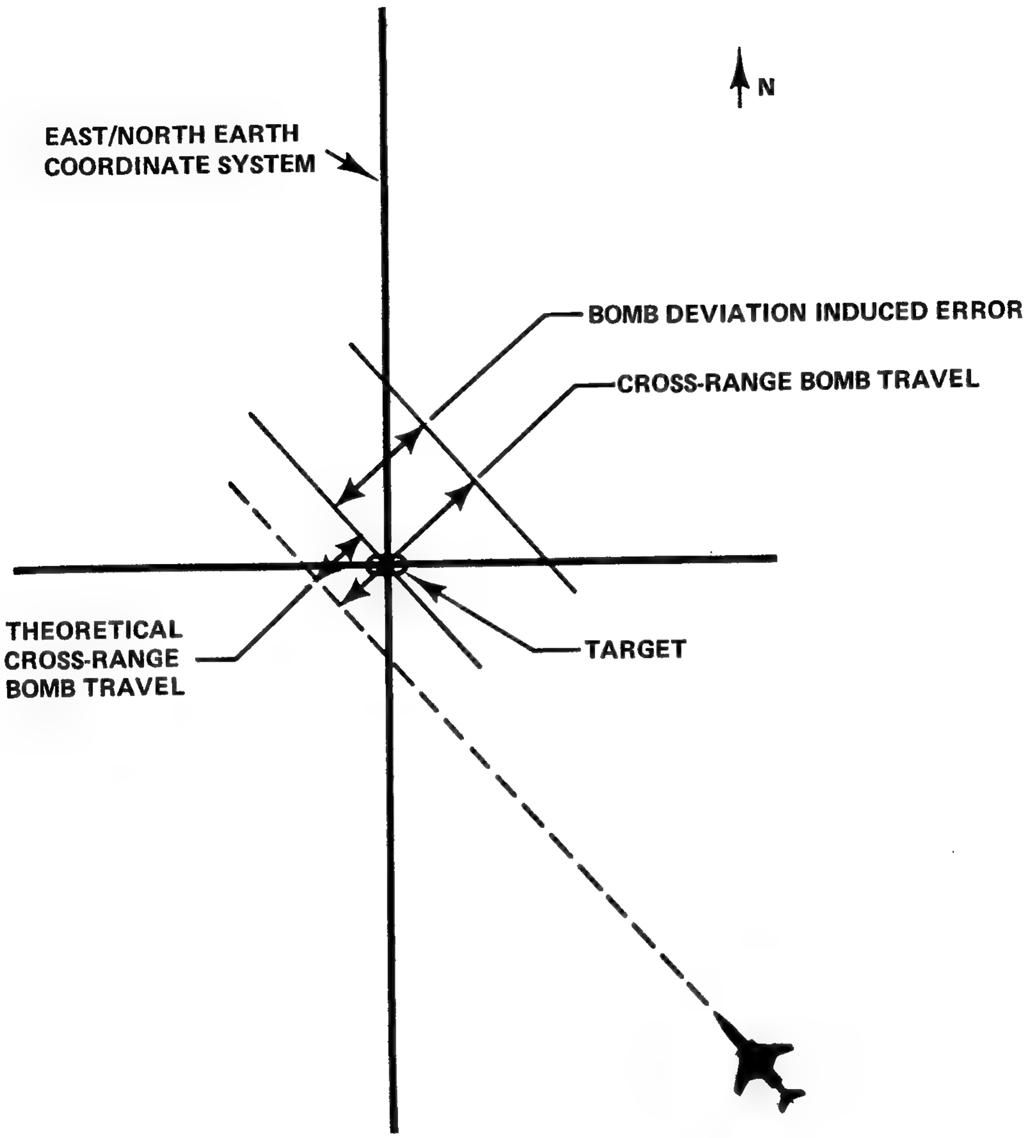

Figure 10
Cross-Range Bomb Deviation

Cross-Range Target Position Error

22. To accurately deliver bombs on target, the weapon system must determine the target position relative to the aircraft. To obtain cross-range target position error, a cross-range target position is first calculated from the instrumented range data by rotating the North and East range in the East/North Earth coordinate system into the Airmass coordinate system. If the aircraft instrumentation system outputs cross-range to target, the cross-range target position can be compared to the weapon system derived cross-range target position. If not, the North range to the

target from instrumented range is compared to the North range to the target derived by the weapon system. Also, the East range to the target from the instrumented range is compared to the East range to the target derived by the weapon system. These two differences can be rotated from the East/North Earth coordinate system into the Airmass coordinate system to obtain the cross-range target position error. Example 15 and figure 11 further explain this procedure.

Example: 15

Given: North distance to the target -6652 ft

East distance to the target 2662 ft

Rotation angle from North/East to Airmass -23.5^{o}

Weapon system North distance to the target 6672 ft

Weapon system East distance to the target -2677 ft

Find weapon system cross-range target position error. First sign of East and North distances are changed to compute the instrumented range in data in the same sign convention as the weapon system.

$$\begin{array}{r} 6672' \\ \underline{-6652'} \\ 20' \end{array} \text{ North range error} \qquad \begin{array}{r} -2677' \\ \underline{-(-)2662'} \\ -15' \end{array} \text{ East range error}$$

Rotate East/North Earth position error into the Airmass coordinate system.

Cross-range error = $(-15 \text{ ft} \cos -23.6^{o} - 20 \text{ ft} \sin -23.6^{o}) = -6$ ft

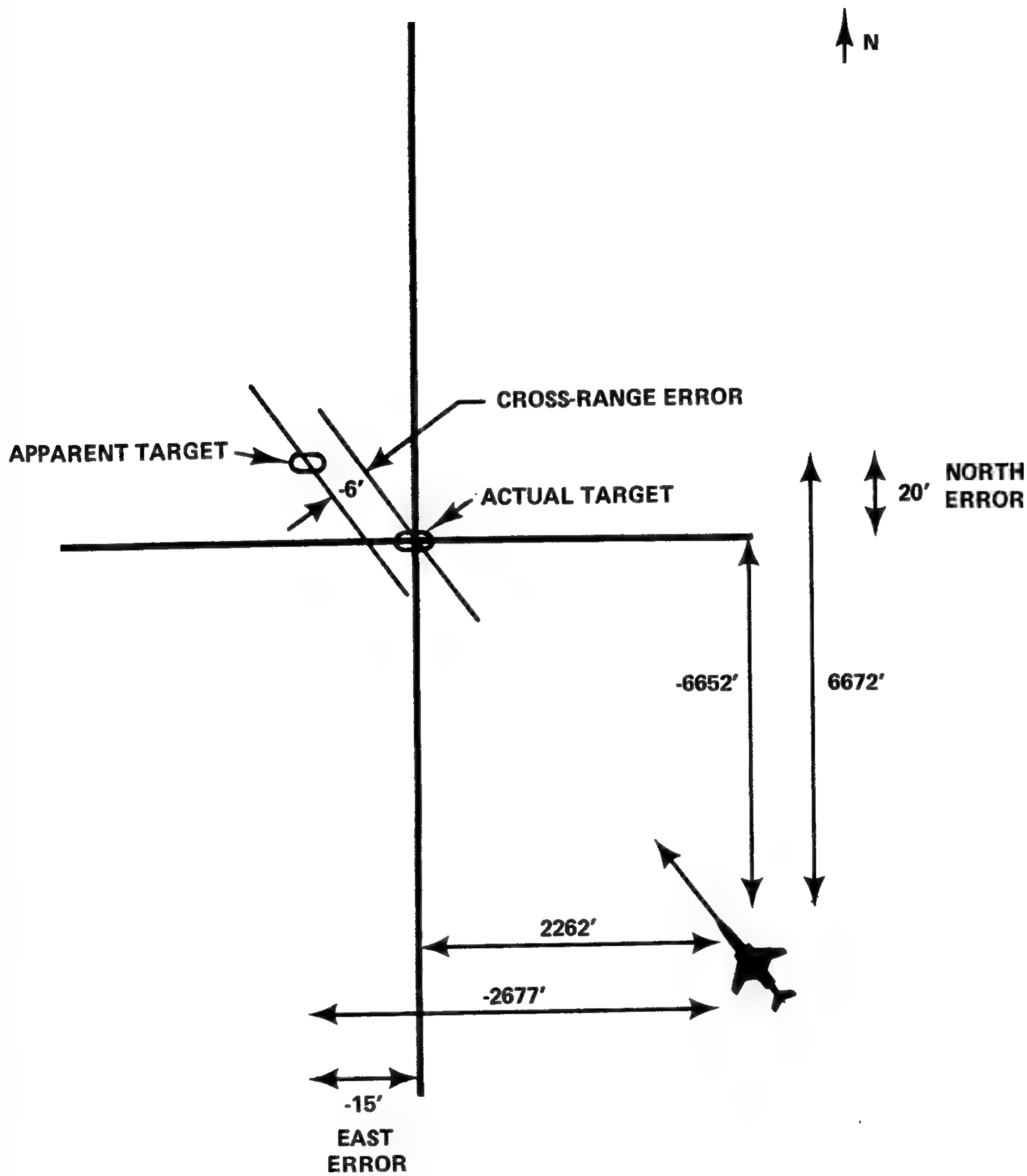

Figure 11
Cross-range Target Position Error

Cross-Range Wind Error

23. To obtain cross-range wind error, the cross-range wind calculated from the instrumented range data and the cross-range wind derived from the weapon system are compared. The wind error is multiplied by time of fall from the instrumented range bomb trajectory calculation to obtain weapon impact error induced by wind error. If the weapon system has no wind solution, the wind error effect is cross-range wind multiplied by time of fall (see example 16).

Example: 16

Given: Cross-range wind 1 ft/sec

Weapon system derived cross-range wind 3 ft/sec

Time of fall 10.5 sec

Find cross-range impact error induced by the 2 ft/sec error.

Wind error effect = 10.5 sec (-2) ft/sec = -21 ft

The sign was changed since the weapon system derived a greater wind and arrived at the release position based on the greater wind. Since actual wind was less than the weapon system derived wind, the aircraft was out of position by 21 ft to the left.

Time of Fall Error

24. It should be apparent that, if the weapon system time of fall calculation is in error, a cross-range weapon impact error will be induced. This error effect is similar to cross-range wind error effect. Time of fall output from the instrumented range trajectory calculation is compared to the time of fall derived by the weapon system. The difference is then multiplied by cross-range wind to derive the effect on the cross-range impact miss distance (see example 17).

Example: 17

Given: Cross-range wind 1 ft/sec

Time of fall 10.5 sec

Weapon system derived time of fall 12.00 sec

Find cross-range impact error induced by the 1.5 sec time of fall error.

Time of fall error effect = -1.5 sec 1 ft/sec = -1.5 ft

The sign was changed since the weapon system derived a greater time of fall and arrived at the release position based upon the greater time of fall. Since the actual time of fall was less than that derived by the weapon system, the aircraft was out of position by 1.5 ft to the left.

Steering Error

25. At release the aircraft should be in a position such that cross-range wind multiplied by time of fall is equal to the cross-range distance to the target derived by the weapon system. If cross-range wind multiplied by time of fall is greater or less than the cross-range distance to the target, the weapon will impact right or left, respectively. This is a steering error since the aircraft was not in the right position in the airmass at release. To calculate steering error subtract aircraft derived cross-range to the target from cross-range wind multiplied by time of fall (see example 18).

Example: 18

Given: Cross-range distance to target 213 ft

Time of fall 12 sec

Cross-range wind = 3 ft/sec

Find steering error

Steering error = (12 sec 3 ft/sec) -213 ft = -177 ft

Total Cross-Range Error

26. The effect on the cross-range component of impact miss distance is the sum of all cross-range error source effects. The total effect on the weapon system, assuming independence, is the sum of all cross-range error source effects less the effect of bomb deviation. Example 19 sums cross-range error source effects.

Example: 19

Given:	Bomb deviation	4.5 ft
	Cross-range target position	-6 ft
	Cross-range wind error	-21 ft
	Time of fall error	-1.5 ft
	Steering error	-177 ft
	Total cross-range error effect	-201 ft

Residual Error

27. Cross-range residual error is calculated in the same manner as in-range residual error (see example 20).

Example: 20

Given: Total cross-range error effect -201 ft

Cross-range component of weapon impact miss distance -207 ft

Find residual error:

Residual error = -201 ft -(-)207 ft = 6 ft

STATISTICS ON ERROR SOURCE EFFECTS

28. Error source effects analysis is a discrete point analysis. Therefore, the error source analysis is done on a release by release basis over a number of weapon delivery runs and statistics are applied to draw conclusions about the data. CEP (reference 1) is the figure of merit used to describe the accuracy of weapon delivery systems. Therefore, the statistics applied to the error source effects should lead to a description of the measured CEP of the weapon system under test. Properly applying statistics to the error source effects determines each individual error source influence on the measured CEP.

29. CEP is calculated from the standard deviation and RMS associated with the two components of the impact miss distance. It follows that a theoretical CEP can be calculated from the error source analysis using the standard deviation and RMS calculated about the total in-range error and the total cross-range error. This theoretical CEP will be within plus or minus 5% of the measured CEP if residual error is small (less than 5% of the impact miss distances). After calculating theoretical CEP, it becomes apparent whether or not an actually measured unacceptable CEP has been caused by total in-range error, total cross-range error, or both. Once this is determined, the individual error source(s) inducing the unacceptable total error can be isolated. Three examples follow that further describe applying statistics to the error source effects.

30. Some definitions are necessary for the three examples. From reference 1:

a. MPI is a measure of location used to determine the centroid of weapon impacts. This parameter is estimated from weapon impacts by the arithmetic means of in-range and cross-range components of weapon impact miss distances.

b. CEP is the radius of a circle that contains 50% of all the impacts and can be calculated about either the target or the MPI.

(1) CEP about the target = 0.5887 X (RMS cross-range error plus RMS in-range error).

(2) CEP about the MPI = 0.5887 X (standard deviation cross-range error plus standard deviation in-range error).

Example: 21

Tables II and III present summary statistics on error source effects, total error, and weapon impact miss distances. The CEP about the target and MPI is calculated from the data in the tables.

CEP about target = 0.5887 (26' + 232') = 152'

CEP about MPI = 0.5887 (25' + 59') = 49'

As noted from the two calculations, the CEP about the target is much larger than the CEP about the MPI. The inference here is that the weapon system grouped the weapons although the group was not on the target. Therefore, further inspection of the data is necessary. Calculate a theoretical CEP about the target and MPI using total error.

Table II

Summary of In-Range Error Source Effects (18 Samples)

Error Source	Error Source Effect (ft)		
	Mean	Standard Deviation	RMS
Bomb Deviation	5	42	44
Target Position	221	25	225
Altitude	-10	32	30
True Airspeed	6	38	40
Flight Path Angle	4	18	21
Wind	3	23	24
Ballistics	-6	15	16
Release Prediction	1	5	6
Total Error	224	51	230
Actual Weapon Miss Distances	222	59	232
Residual Error	2	4	4

NOTES: Sign Convention on Error Effects
+ right or long
- left or short

Table III

Summary of Cross-Range Error Source Effects (18 Samples)

Error Source	Error Source Effect (ft)		
	Mean	Standard Deviation	RMS
Bomb Deviation	21	15	31
Target Position	-32	28	39
Wind	25	10	28
Time of Fall	-15	8	18
Steering	-8	3	9
Total Error	-9	17	28
Actual Weapon Miss Distances	-10	25	26
Residual Error	1	2	3

NOTES: Sign Convention on Error Effects
+ right or long
- left or short

Theoretical CEP about target = 0.5887 (28' + 230') = 152'

Theoretical CEP about MPI = 0.5887 (17' + 51') = 40'

These two calculations also exhibit the same grouping as the weapon impacts. Also note that the in-range total error has the greater influence (230 ft as compared to 28 ft). Therefore, an in-range error source is causing the large CEP about the target. The error source can be found by examining the in-range summary statistics table. Target position error effect exhibits a mean of 221 ft causing the total error bias. Also, the RMS of target position error is 225 ft having the greatest influence on total error.

Example: 22

Tables IV and V present summary statistics in error source effects, total error, and weapon impact miss distances. The CEP about the target and MPI is calculated from the data in the tables.

Table IV

Summary of In-Range Error Source Effects (18 Samples)

Error Source	Error Source Effect (ft)		
	Mean	Standard Deviation	RMS
Bomb Deviation	13	40	42
Target Position	8	22	23
Altitude	-9	22	25
True Airspeed	-15	41	43
Flight Path Angle	3	14	15
Wind	-1	208	210
Ballistics	5	15	16
Release Prediction	1	5	5
Total Error	4	198	200
Actual Weapon Miss Distances	6	199	201
Residual Error	-2	5	6

NOTES: Sign Convention on Error Effects
+ right or long
- left or short

Table V

Summary of Cross-Range Error Source Effects (18 Samples)

Error Source	Error Source Effect (ft)		
	Mean	Standard Deviation	RMS
Bomb Deviation	-28	15	32
Target Position	15	7	16
Wind	38	20	41
Time of Fall	-10	10	15
Steering	-5	2	7
Total Error	10	10	11
Actual Weapon Miss Distances	12	14	13
Residual Error	-2	2	3

NOTES: Sign Convention on Error Effects
+ right or long
- left or short

CEP about target = 0.5887 (13' + 201') = 126'

CEP about MPI = 0.5887 (14' + 199') = 125'

In this case the CEP about the target is almost equal to the CEP about MPI. The inference drawn here is that, even though no bias exists, the weapon impacts are highly dispersed about the target. Therefore, further inspection of the data is necessary to isolate the error source(s) inducing the dispersion. A theoretical CEP is calculated about the target and MPI using total error.

Theoretical CEP about target = 0.5887 (11' + 200') = 124'

Theoretical CEP about MPI = 0.5887 (10' + 198') = 122'

These two calculations also exhibit the same grouping as the weapon impacts. Also noted is that the in-range total error has the greater influence (200 ft as compared to 11 ft). Therefore, an in-range error source is causing the large CEP about the target and large CEP about the MPI. The error source can be found by examining the in-range summary statistics table. Wind error effect exhibits a standard deviation of 208 ft and an RMS of 210 ft which exerts the greatest influence on total error dispersion (standard deviation and RMS).

Example: 23

Tables VI and VII present summary statistics on error source effects, total error, and weapon impact miss distances. The CEP about the target and MPI is calculated from the data in the tables.

CEP about target = 0.5887 (13' + 47') = 35'

CEP about MPI = 0.5887 (8' + 45') = 31'

In this case, the CEP about the target is almost equal to the CEP about the MPI and both, for a current state-of-the-art weapon system, are of a satisfactory size. Although the accuracy was satisfactory, further inspection of the data is necessary to determine whether anomalies exist. By examining both tables VI and VII, large errors can be found in the in-range summary statistics. Altitude and wind exhibit large mean error source effects although they offset one another. If this weapon system is left untouched, it would perform satisfactorily. The system could degrade significantly if either a new altitude or wind sensing device were installed. In such a case, an improvement in one or the other sensing device could cause the overall weapon system accuracy to degrade by up to 236 ft in-range bias.

31. The three previous examples demonstrated the usual classification of error source effects in a weapon system evaluation. Typically, some combination of these examples exist; however, this technique of isolating and examining error sources will determine their effect on measured CEP.

Table VI

Summary of In-Range Error Source Effects (18 Samples)

Error Source	Error Source Effect (ft)		
	Mean	Standard Deviation	RMS
Bomb Deviation	-6	40	41
Target Position	25	18	26
Altitude	232	32	238
True Airspeed	-15	21	22
Flight Path Angle	1	14	15
Wind	-236	40	240
Ballistics	-10	20	23
Release Prediction	1	2	3
Total Error	-8	48	50
Actual Weapon Miss Distances	-6	45	47
Residual Error	-2	6	6

NOTES: Sign Convention on Error Effects
+ right or long
- left or short

Table VII

Summary of Cross-Range Error Source Effects (18 Samples)

Error Source	Error Source Effect (ft)		
	Mean	Standard Deviation	RMS
Bomb Deviation	30	13	31
Target Position	7	11	12
Wind	-21	8	22
Time of Fall	-8	3	8
Steering	3	3	4
Total Error	11	6	12
Actual Weapon Miss Distances	10	8	13
Residual Error	1	2	3

NOTES: Sign Convention on Error Effects
+ right or long
- left or short

CONCLUSIONS

GENERAL

32. This technique of identifying, isolating, and examining error source effects has already proven useful in past weapon system evaluations.

SPECIFIC

33. Weapon impact miss distance can be described in terms of error source effects.

34. Weapon system analysis is necessary to isolate and examine error source effects.

35. An instrumented aircraft and test flight flown on an instrumented range are required to permit weapon system analysis.

36. Applying statistics to the error source effects determines each individual error source influence on the measured CEP.

37. Error source effects fall into three categories: bias, dispersion, or compensating errors; however, some combination of the three usually exists.

REFERENCES

1. Nowak, Raymond E., Statistical Analysis of Weapon Impact Data, TM 78-4 SA, of 12 May 1978.

DISTRIBUTION:

NAVAIRTESTCEN (CT02)	(1)
NAVAIRTESTCEN (CT03)	(1)
NAVAIRTESTCEN (CT84)	(1)
NAVAIRTESTCEN (SA50)	(20)
NAVAIRTESTCEN (SA04)	(1)
NAVAIRTESTCEN (SY04)	(1)
NAVAIRTESTCEN (AT04)	(1)
NAVAIRTESTCEN (TS02)	(1)
NAVAIRTESTCEN (CS03)	(1)
NAVAIRTESTCEN (RW04)	(1)
NAVAIRTESTCEN (TP40)	(20)